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(54) SYSTEMS AND METHODS FOR CONTROLLING NOISE IN A VEHICLE

(71) Applicant: GM GLOBAL TECHNOLOGY OPERATIONS LLC, Detroit, MI (US)

(72) Inventors: Eli Tzirkel-Hancock, Ra'anana (IL); Scott M. Reilly, Southfield, MI (US)

(73) Assignee: GM GLOBAL TECHNOLOGY OPERATIONS LLC, Detroit, MI (US)

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G10K 11/175 (2006.01)
G10L 21/0208 (2013.01)

(52) U.S. Cl.
CPC ***G10K 11/175*** (2013.01); ***G10L 21/0208*** (2013.01); *G10K 2210/128* (2013.01); *G10K 2210/1281* (2013.01); *G10K 2210/1282* (2013.01)

(58) Field of Classification Search
CPC G10K 2210/128; G10K 2210/1281; G10K 2210/1282; G10K 11/175
USPC 381/71.1–71.4, 71.6, 71.12
See application file for complete search history.

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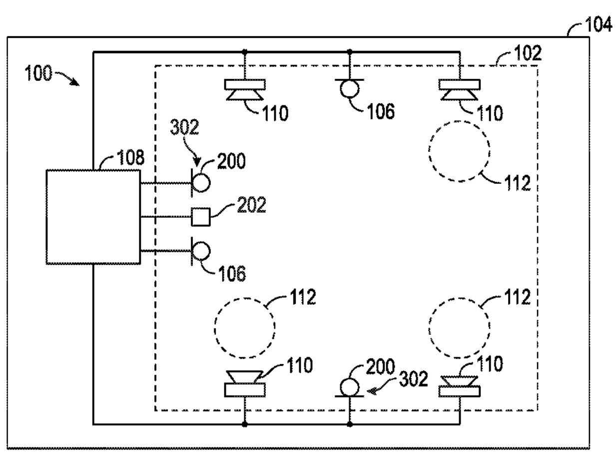
Primary Examiner — Disler Paul
(74) *Attorney, Agent, or Firm* — Lorenz & Kope, LLP

(57) ABSTRACT

Methods and apparatus are provided for controlling noise in a compartment. The audio system includes an error microphone configured to receive sounds and generate an error signal corresponding to the received sounds. A processor in communication with the error microphone is configured receive the error signal from the error microphone and generate a noise-canceling signal based at least in part on the error signal and an acoustic transfer function. The audio system also includes a loudspeaker in communication with the processor to receive the noise-canceling signal and produce a noise-canceling sound wave based on the noise-canceling signal. The processor is also configured to receive at least one audio signal different from the error signal and to modify the acoustic transfer function utilizing the at least one audio signal.

17 Claims, 3 Drawing Sheets



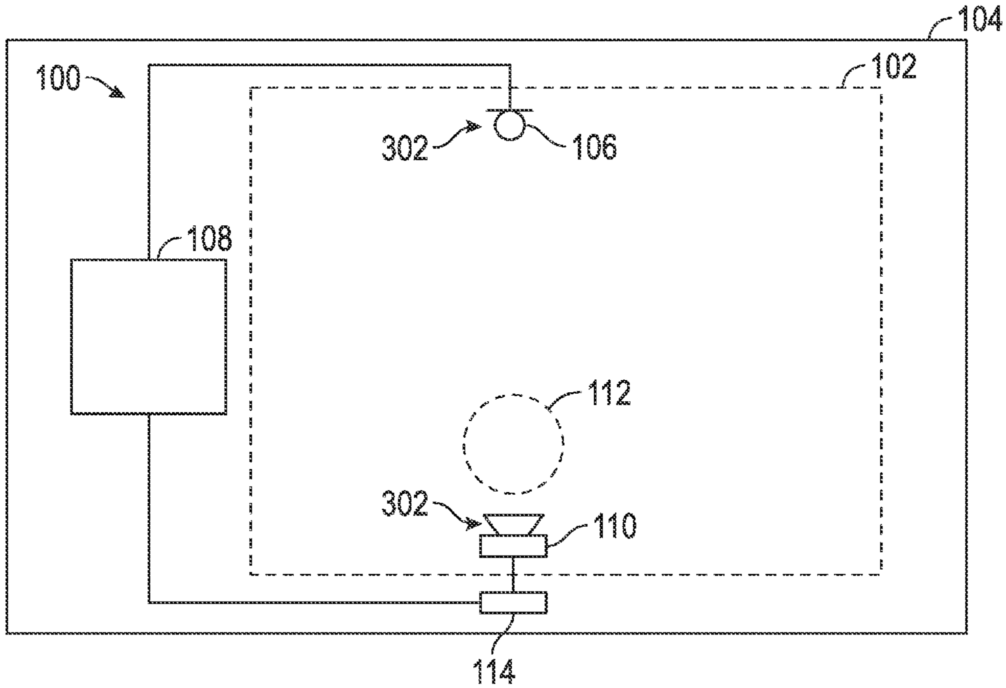

104
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FIG. 1

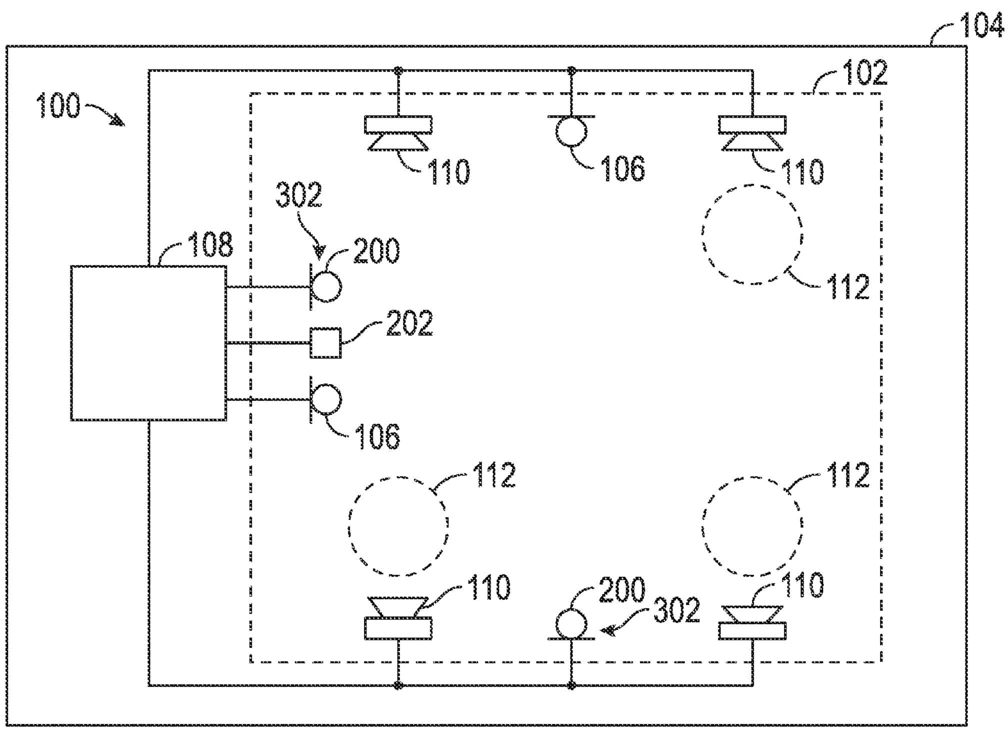
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FIG. 2

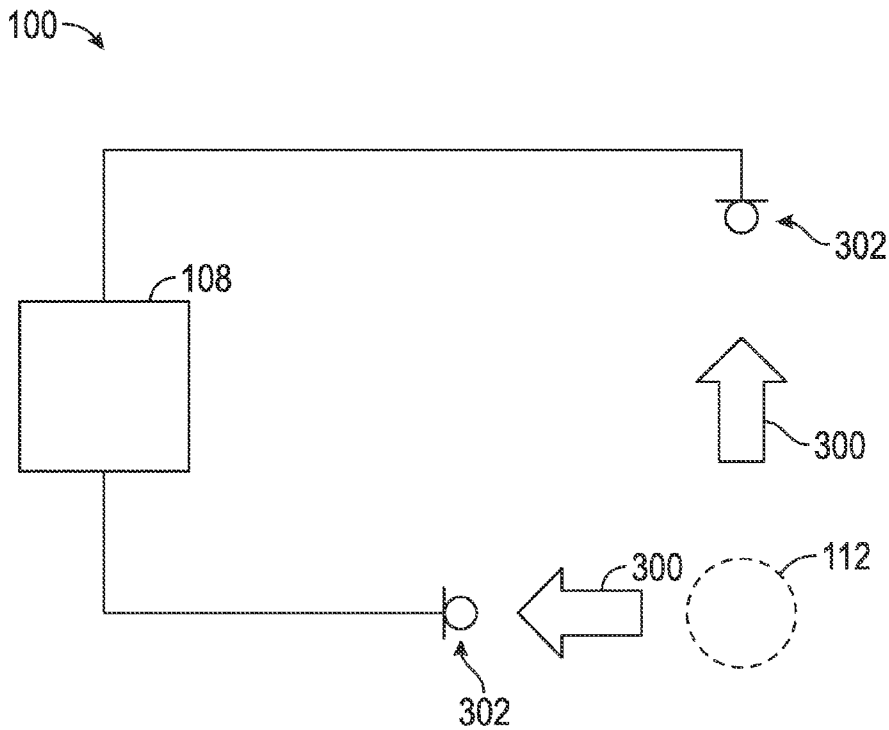

FIG. 3

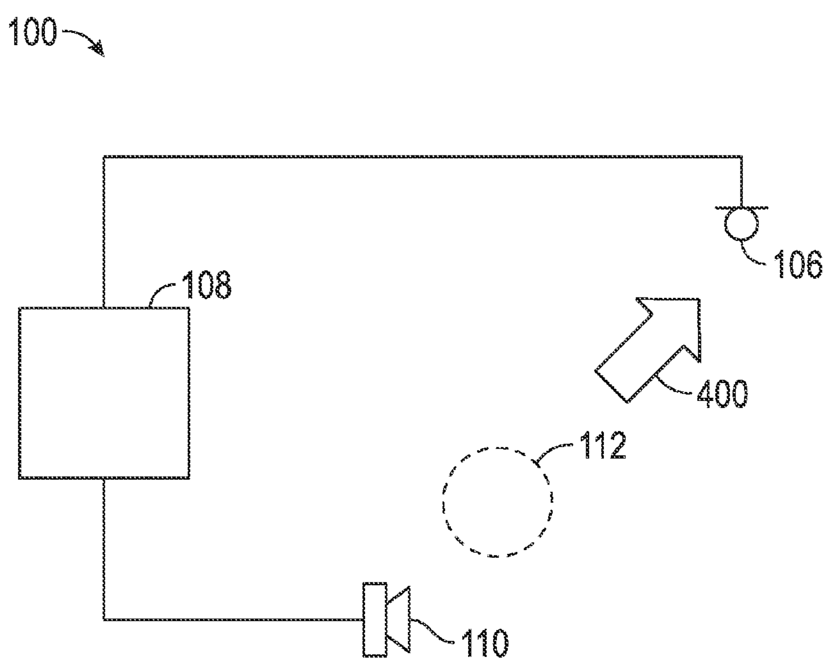

FIG. 4

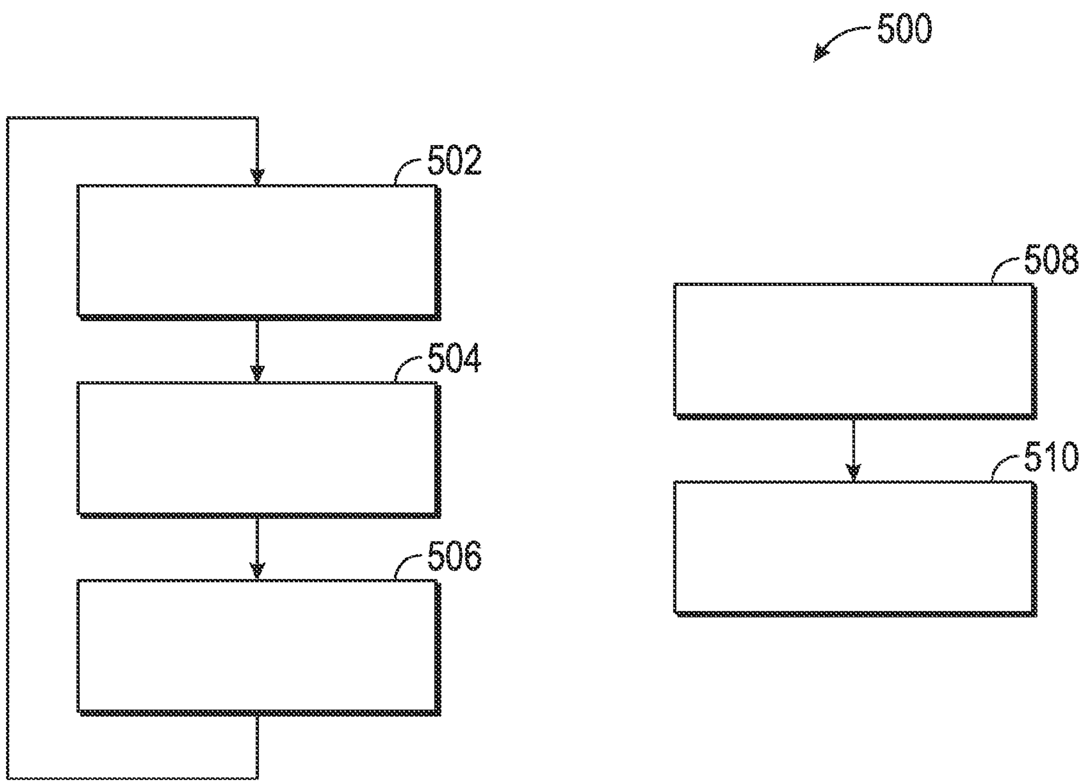

FIG. 5

SYSTEMS AND METHODS FOR CONTROLLING NOISE IN A VEHICLE

TECHNICAL FIELD

The technical field generally relates to systems and methods for controlling noise in a vehicle, more particularly to active noise control systems and methods for a motor vehicle.

BACKGROUND

Active noise control ("ANC") systems may be implemented in a motor vehicle, e.g., an automobile, to reduce the amount of noise and undesired sounds that occupants are subjected to. Such systems typically include a microphone to receive noise and at least one loudspeaker to produce an inverted signal corresponding to the noise to be canceled. The ANC system may utilize a transfer function, specifically an acoustic transfer function, to mathematically represent the spatial characteristics of a cabin of the vehicle. In generating a noise canceling signal that is sent to the loudspeaker, the ANC system utilizes a signal generated by the microphone and the acoustic transfer function.

The acoustic transfer functions utilized in many prior art ANC systems are estimated at vehicle development time and remain fixed thereafter. As such, the ANC systems may not be able to account for changing conditions of the cabin including, but not limited to, the number of occupants, the position of the occupants, and aging of the components of the cabin. Accordingly, overall performance of the ANC system suffers.

Accordingly, it is desirable to provide systems and methods for variably controlling noise in a cabin of a vehicle. Furthermore, other desirable features and characteristics of the present invention will become apparent from the subsequent detailed description and the appended claims, taken in conjunction with the accompanying drawings and the foregoing technical field and background.

SUMMARY

In one embodiment, an audio system includes an error microphone configured to receive sounds and generate an error signal corresponding to the received sounds. A processor in communication with the error microphone is configured receive the error signal from the error microphone and generate a noise-canceling signal utilizing the error signal and an acoustic transfer function. The audio system also includes a loudspeaker in communication with the processor to receive the noise-canceling signal and produce a noise-canceling sound wave based on the noise-canceling signal. The processor is also configured to receive at least one audio signal different from the error signal and to modify the acoustic transfer function utilizing the at least one audio signal.

In one embodiment, a method is provided for controlling noise in a compartment. The method includes receiving an error signal from an error microphone. The method also includes generating a noise-canceling signal based at least in part on the error signal and an acoustic transfer function. A noise-canceling sound wave is produced from a loudspeaker based on the noise-canceling signal. The method further includes receiving at least one audio signal different from the error signal. The acoustic transfer function is modified utilizing the at least one audio signal.

DESCRIPTION OF THE DRAWINGS

The exemplary embodiments will hereinafter be described in conjunction with the following drawing figures, wherein like numerals denote like elements, and wherein:

FIG. **1** is a block electrical diagram of a vehicle including a system for controlling noise in accordance with various embodiments;

FIG. **2** is a block electrical diagram of the vehicle including the system with a plurality of speakers and error microphones in accordance with various embodiments;

FIG. **3** is a block diagram of the system in accordance with various embodiments showing a plurality of speech sound waves;

FIG. **4** is a block diagram of the system in accordance with various embodiments showing a known audio signal; and

FIG. **5** is a flowchart of a method for controlling noise in accordance with various embodiments.

DETAILED DESCRIPTION

The following detailed description is merely exemplary in nature and is not intended to limit the application and uses. Furthermore, there is no intention to be bound by any expressed or implied theory presented in the preceding technical field, background, brief summary or the following detailed description.

Referring to the figures, wherein like numerals indicate like parts throughout the several views, an audio system **100** and method **500** of controlling noise in a compartment **102**, e.g., a passenger compartment or a cabin, are shown and described herein. In the exemplary embodiment, the compartment **102** is part of a vehicle **104** and the vehicle **104** is an automobile (not separately numbered). It should be appreciated, however, that the system **100** and/or method **500** described herein may be implemented in other types of vehicles **104**, including, but not limited to, aircraft and watercraft. Furthermore, the system **100** and method **500** may be implemented in non-vehicle applications, e.g., an office environment.

Referring to FIG. **1**, the audio system **100** includes at least one error microphone **106** configured to receive sounds. The system may **100** include multiple error microphones **106**, such as in the exemplary embodiment shown in FIG. **2**. However, for ease of readability, the error microphones **106** may be referred to a single error microphone **106** herein. Microphones generate signals corresponding to sounds they receive, as is appreciated by those skilled in the art. Specifically, in the audio systems **100** described herein, the error microphone **106** generates an error signal corresponding to the received sounds.

The audio system **100** also includes a processor **108**. The processor **108** of the exemplary embodiments is implemented with at least one semiconductor-based microprocessor capable of performing calculations and executing instructions (i.e., running a program). The processor **108** of the exemplary embodiments includes a digital signal processor ("DSP") configured to convert and process analog signals. However, it should be appreciated that the processor **108** may be implemented with any number of suitable devices, schemes, or configurations, as is readily appreciated by those skilled in the art.

The processor **108** is in communication with the error microphone and is configured to receive the error signal from the error microphone **106**. The processor **108** is configured to generate a noise-canceling signal based at least in part on an error signal and an acoustic transfer function. One possible acoustic transfer function may be expressed as $a(\omega)\cdot\exp(-j\cdot p(\omega)))$ where ω is a certain frequency, $a(\omega)$ is the acoustic path attenuation at that frequency, and $p(\omega)$ is the phase shift at that frequency. It should be appreciated that generating the noise-canceling signal may utilize an acoustic transfer functions either directly or indirectly. For example, utilizing an acoustic transfer function indirectly may be utilized with an inverse system.

The audio system **100** also includes at least one loudspeaker **110**, as shown in FIG. **1**. Of course, multiple loudspeakers **110** may be implemented, as is shown in FIG. **2**. However, for ease of readability, the loudspeakers **110** may be referred to a single loudspeaker **110** herein. Loudspeakers generate sounds corresponding to signals they receive, as is appreciated by those skilled in the art. Specifically, in the audio systems **100** described herein, the loudspeaker **110** generates a noise-canceling sound corresponding to the received noise-canceling signal.

The processor **108** is also configured to modify the acoustic transfer function to compensate for variability in the passenger compartment **102**. These variabilities may include, but are certainly not limited to, the presence and/or location of occupants **112**, the presence and/or location of other objects (not shown), and the aging of materials and/or other components forming the compartment **102**.

In one example, the processor **108** is also configured to receive at least one audio signal different from the error signal from the error microphone **106**. The processor **108** is further configured to modify the acoustic transfer function based at least in part on the at least one audio signal, as described in greater detail below.

In one embodiment, the processor **108** is configured to modify the acoustic transfer function utilizing speech produced by at least one of the occupants **112**. More specifically, the processor **108** is configured to modify the acoustic transfer function based at least partially on the location of the occupant **112** that is speaking. The location of the occupant **112** need not be specifically determined, but rather a generalized or rough location may be utilized. An example of determining such a location is described further below.

In this embodiment, as shown in FIG. **3**, speech sounds waves **300** are received at a plurality of audio input devices **302**. The audio input devices **302** are disposed apart from one another, as also shown in FIG. **3**. Each audio input device **302** generates a speech audio signal corresponding to the received speech sound waves. As such, multiple speech audio signals are generated by the audio input devices **302**.

The audio input devices **302** may be implemented using various apparatuses. In the embodiment shown in FIG. **1**, the audio input devices **302** are implemented with the error microphone **106** and the loudspeaker **110**. In order to utilize the loudspeaker **110** as an audio input device **302**, the system **100** includes a conditioning circuit **114** electrically coupled between the loudspeaker **110** and the processor **108**. The conditioning circuit **114** is configured to generate one of the speech audio signals in response to the speech sound wave being received by the loudspeaker **110**.

The audio input devices **302** may also be implemented using the error microphone **106**. As such, the error microphone **106** that generates the error signal may also generate one of the speech audio signals. Of course, the error microphone **106** may simply generate one signal that is then sent to the processor **108**, without internally differentiating between whether that signal is generated by noise (i.e., the error signal) or by speech of an occupant (i.e., the speech audio signal). The processor **108** may be configured to separate one signal from the error microphone **106** into the error signal and the speech audio signal. For instance, the processor **108** may be configured to sense speech patterns, i.e., the speech audio signal, and isolate those patterns accordingly. This may be accomplished by filtering out noise from the error signal provided by the error microphone **106**, e.g., by using a notch filter to remove engine noise.

The audio input devices **302** may also be implemented with one or more additional microphones **200**, separate from the error microphone **106** and/or the loudspeaker **110**, as shown in FIG. **2**. Each additional microphone **200** generates a speech audio signal which may be communicated to the processor **108**.

In the embodiments shown in FIGS. **1-3**, and as stated above, the processor **108** is configured to receive a plurality of speech audio signals different from the error signal. The processor **108** is also configured to modify the acoustic transfer function based at least in part on the plurality of speech audio signals.

In one technique, modifying the acoustic transfer function includes determining a location of the occupant **112** based on the plurality of speech sound waves and corresponding speech audio signals. Determining the location of the occupant **112** may be accomplished by comparing the timing of the different speech audio signals received from different audio input devices **302** with knowledge of the position of the audio input devices **302** with respect to the passenger compartment **102**. That is, the location of the occupant **112** may be triangulated using the speech sound waves and known positions of the audio input devices **302**.

To better determine the location of the occupant **112**, the processor **108** may also be configured to determine that only one occupant **112** is speaking. Specifically, the processor **108** executes digital signal processing routines to determine if more than one speech pattern exists in the speech audio signals. In such a configuration, the processor **108** determines the position of the occupant **112** in response to the determination that only one occupant is speaking. For example, this can be based on signal level at the microphones **106**. If the level in one microphone **106** is higher it may be concluded that only the speaking occupant **112** near that microphone **106** is active. Alternatively, delay and sum beamforming for the occupants **112** may be utilized.

By utilizing the location of the occupants **112**, the system **100** can tailor noise-canceling signals and sounds for the particular occupants **112**. As such, one loudspeaker **110** can emit a first noise-canceling signal and another loudspeaker **110** can emit a second noise-canceling signal in order to reduce the noise heard by the particular occupants **112**.

The system **100** can further include a position sensor **202**, as shown in FIG. **2**. The position sensor **202** is in communication with the processor **108** and configured to determine more precise locations of the occupants **112**. For example, the position sensor **202** may be a camera, radar system, sonar system, and/or a weight sensor. Of course, other techniques for implementing the position sensor **202** may be employed.

The acoustic transfer function may include a scale factor, as is appreciated by those skilled in the art. Modifying the scale factor will modify the acoustic transfer function. As such, the processor **108** may modify the scale factor based at least in part on the plurality of speech audio signals.

In another embodiment, as shown in FIG. **4**, the processor **108** is configured to modify the acoustic transfer function based at least partially on a comparison between a received audio signal and a known audio signal **400**. Specifically, the system **100** is configured to produce a known audio signal with the loudspeaker **110**. This known audio signal **400** can be generated using a signal that is normally in use, e.g., a radio broadcast. Alternatively, the known audio signal **400** can be delivered coincidental to the radio signal, i.e., the known audio signal **400** could be masked by the radio signal, such that the occupant **112** may not notice the generation of the known audio signal **400** by the loudspeaker **110**.

The system **100** of this embodiment is also configured to generate a received audio signal corresponding to the known audio signal. In the embodiment shown in FIG. **5**, the error microphone **106** can be configured to generate the received audio signal, which is then sent to the processor **108**. The processor **108** is configured to compare the received audio signal to the known audio signal **400** and then modify the acoustic transfer function based at least in part on the comparison between the received audio signal and the known audio signal. The comparison between the received audio signal and the known audio signal may be accomplished by comparing attenuation and phase shift at different frequencies.

For instance, when occupants **112** and other articles are placed in the passenger compartment **102** of the vehicle **104**, they will affect the acoustic dynamics of the compartment **102**. Accordingly, the transfer of the known audio signal **400** to the received audio signal will be altered by changes in the passenger compartment **102**. The processor **108** is configured to compare the differences between the known and received audio signals and to modify the acoustic transfer function to compensate.

The method **500** of controlling noise in the passenger compartment **102** of the vehicle **104** may be better appreciated with reference to FIG. **5**. In block **502**, the method **500** includes receiving an error signal from an error microphone **106**. The method **500** continues, at **504**, with generating a noise-canceling signal based at least in part on the error signal and an acoustic transfer function. The method **500** further includes, at **506**, producing a noise-canceling sound wave from a loudspeaker based on the noise-canceling signal. This process (**502**, **504**, and **506**) repeats itself as long as noise control is desired, e.g., whenever the vehicle **104** is operating.

Before, during, or after the noise control process (**502**, **504**, and **506**) described above, the method **500** also includes, at **508**, receiving at least one audio signal different from the error signal. As described above, in one embodiment, the at least one audio signal may be a plurality of speech audio signals produced by the occupant **112**. In another embodiment, the at least one audio signal may be a known audio signal **400**.

The method **500** further includes, at **510**, modifying the acoustic transfer function based at least in part on the at least one audio signal. In one embodiment, the acoustic transfer function is modified based on the presence or location of the occupant **112** as determined by comparing the plurality of speech audio signals. In another embodiment, the difference between the known and received signals is utilized to modify the acoustic transfer function.

While at least one exemplary embodiment has been presented in the foregoing detailed description, it should be appreciated that a vast number of variations exist. It should also be appreciated that the exemplary embodiment or exemplary embodiments are only examples, and are not intended to limit the scope, applicability, or configuration of the disclosure in any way. Rather, the foregoing detailed description will provide those skilled in the art with a convenient road map for implementing the exemplary embodiment or exemplary embodiments. It should be understood that various changes can be made in the function and arrangement of elements without departing from the scope of the disclosure as set forth in the appended claims and the legal equivalents thereof.

What is claimed is:

1. A method of controlling noise in a compartment, comprising:
- receiving an error signal from an error microphone;
- generating a noise-canceling signal based at least in part on the error signal and an acoustic transfer function;
- producing a noise-canceling sound wave from a loudspeaker based on the noise-canceling signal;
- receiving at least one audio signal different from the error signal;
- receiving speech sound waves at a plurality of audio input devices;
- generating a plurality of audio signals with the plurality of audio input devices different from the error signal;
- determining a location of an occupant generating the speech sound waves based on the plurality of audio signals; and
- modifying the acoustic transfer function based on the plurality of audio signals and the location of the occupant.

2. The method as set forth in claim **1**, wherein receiving speech sound waves comprises receiving a speech sound wave at the error microphone.

3. The method as set forth in claim **1**, wherein receiving speech sound waves comprises receiving a speech sound wave at the loudspeaker.

4. The method as set forth in claim **1**, wherein receiving speech sound waves comprises receiving a speech sound wave at an additional microphone.

5. The method as set forth in claim **1**, further comprising determining when only one occupant is speaking; and
- wherein determining a location of an occupant generating the speech sound waves is further defined as determining a location of the occupant generating the speech sound waves based on the plurality of audio signals in response to the determination that only one occupant is speaking.

6. The method as set forth in claim **1**, further comprising:
- producing a known audio signal with the loudspeaker;
- generating a received audio signal with the error microphone corresponding to the known audio signal;
- wherein modifying the acoustic transfer function comprises:
  - comparing the received audio signal to the known audio signal; and
  - modifying the acoustic transfer function utilizing the comparison between the received audio signal and the known audio signal.

7. The method as set forth in claim **1** wherein the acoustic transfer function includes a scale factor and wherein modifying the acoustic transfer function is further defined as modifying the scale factor based on the plurality of audio signals.

8. An audio system, comprising:
- an error microphone configured to receive sounds and generate an error signal corresponding to the received sounds;
- a processor in communication with said error microphone and configured to:
  - receive the error signal from said error microphone;
  - generate a noise-canceling signal based on the error signal and an acoustic transfer function; and

a loudspeaker in communication with said processor to receive said noise-canceling signal and produce a noise-canceling sound wave based on the noise-canceling signal,

wherein said processor is further configured to:

receive at least one audio signal different from the error signal, the at least one audio signal further defined as a plurality of audio signals corresponding to speech sound waves;

determine a location of an occupant generating the speech sound waves based on the plurality of audio signals; and

modify the acoustic transfer function based on the plurality of audio signals and the location of the occupant.

9. The audio system as set forth in claim **8**, wherein said error microphone is configured to receive at least one speech sound wave and generate at least one of the plurality of audio signals.

10. The audio system as set forth in claim **8**, further comprising a conditioning circuit electrically coupled between said loudspeaker to said processor and configured to generate at least one of the plurality of audio signals in response to at least one speech sound wave received by said loudspeaker.

11. The audio system as set forth in claim **8**, further comprising an additional microphone in communication with said processor and configured to generate at least one of the plurality of audio signals in response to receiving at least one speech sound wave.

12. The audio system as set forth in claim **8**, wherein said processor is further configured to:

determine when only one occupant is speaking; and

determine the location of the occupant generating the speech sound waves based on the plurality of audio signals in response to the determination that only one occupant is speaking.

13. The audio system as set forth in claim **8**,

wherein said loudspeaker is configured to produce a known audio signal;

wherein said error microphone is configured to generate a received audio signal with corresponding to the known audio signal;

wherein said controller modifies the acoustic transfer function by:

comparing the received audio signal to the known audio signal; and

modifying the acoustic transfer function utilizing the comparison between the received audio signal and the known audio signal.

14. The audio system as set forth in claim **8**, wherein the acoustic transfer function includes a scale factor and wherein said processor is configured to modify the scale factor based on the plurality of audio signals.

15. A vehicle, comprising:

a passenger compartment; and

an audio system comprising:

an error microphone configured to receive sounds within the passenger compartment and generate an error signal corresponding to the received sounds;

a processor in communication with said error microphone and configured to:

receive the error signal from said error microphone;

generate a noise-cancelling signal based on the error signal and an acoustic transfer function; and

a loudspeaker in communication with said processor to receive said noise-canceling signal and produce a noise-cancelling sound wave based on the noise-cancelling signal;

wherein the at least one audio signal is further defined as a plurality of audio signals corresponding to speech sound waves and said processor is further configured to:

receive at least one audio signal different from said error signal;

modify the acoustic transfer function based at least in part of the at least one audio signal;

determine a location of an occupant generating the speech sound waves based on the plurality of audio signals; and modify the acoustic transfer function based on the location of the occupant.

16. The vehicle as set forth in claim **15**, said error microphone is configured to receive at least one speech sound wave and generate at least one of the plurality of audio signals.

17. The vehicle as set forth in claim **15**, further comprising a conditioning circuit electrically coupled between said loudspeaker to said processor and configured to generate at least one of the plurality of audio signals in response to at least one speech sound wave received by said loudspeaker.

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